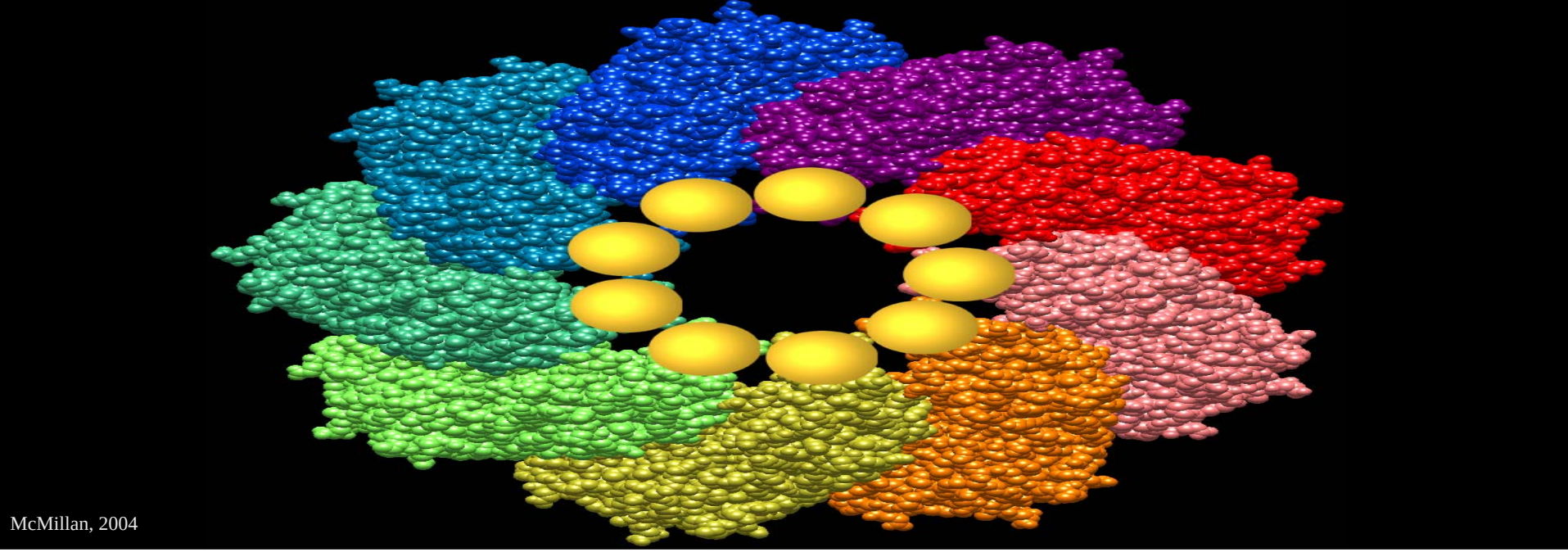


National Nanotechnology Initiative

Overview

Dr. M.C. Roco

Chair, Subcommittee on Nanoscience, Engineering and Technology (NSET), NSTC
Senior Advisor for Nanotechnology, National Science Foundation

Research Directions II

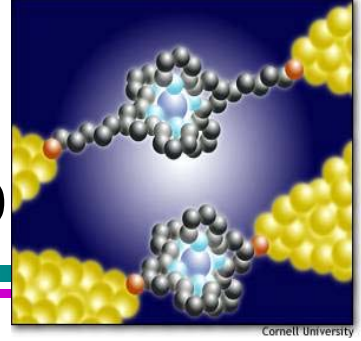
September 8, 2004

Topics

- **NNI program and timeline**
- **Major changes in the first four years**
- **Setting new goals in 2004**
- **The international context**

Nanotechnology

Definition on www.nano.gov/omb_nifty50.htm (2000)



- **Working at the atomic, molecular and supramolecular levels, in the length scale of approximately 1 – 100 nm range, in order to understand, create and use materials, devices and systems with fundamentally new properties and functions because of their small structure**

- **NNI definition encourages new contributions that were not possible before**

  - novel phenomena, properties and functions at nanoscale, which are nonscalable outside of the nm domain

  - the ability to measure / control / manipulate matter at the nanoscale in order to change those properties and functions

  - integration along length scales, and fields of application

NNI - Why nanotechnology is important?

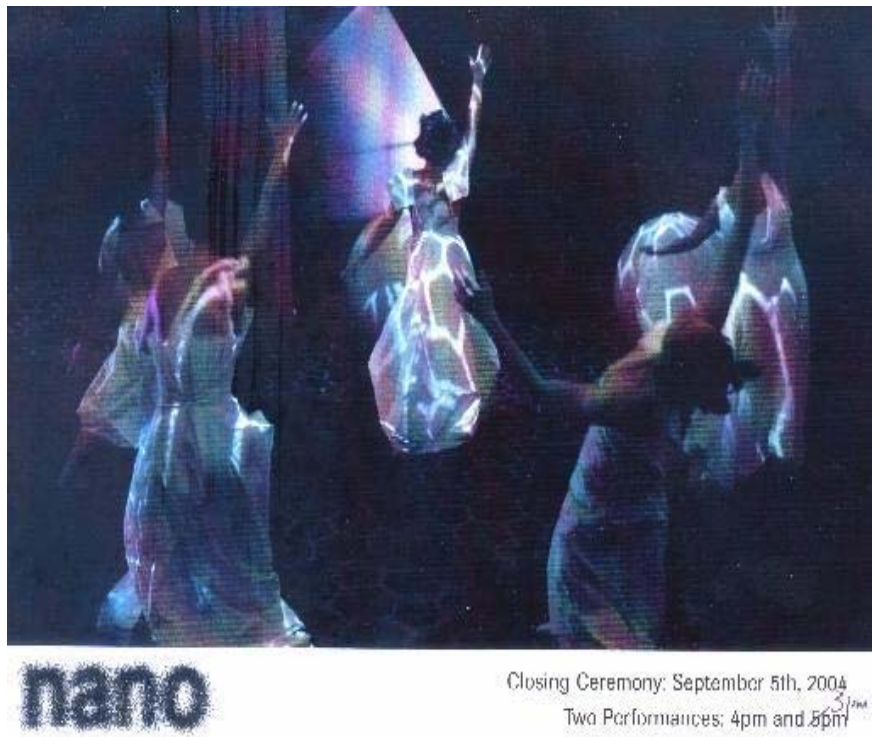
- **Reaching at the foundation of matter**
  Historical event in understanding, control and transformation of natural/living and manmade systems (natural threshold)

- **The long term societal implications – driver 2000**
  Improved knowledge, quality of life, and environment
  Create foundation for a new industrial revolution

- **Higher purpose goals than development of NT**
  - More basic and unifying science and education
  - Higher efficiency processes and novel products
  - Molecular medicine
  - Extend the limits of sustainable development
  - Increased coherence/integration of S&T policies

Nanotechnology development cannot be decided only by nanotechnologists

Nanotechnology will broadly affect society, from new products to art



R&D towards the Next Industrial Revolution

1999 metrics, 2004 check the progress, 2015 to satisfy first criteria

The concept:

Changing the foundation of understanding, manufacturing and medicine from the macro and micro domains to the nanoscale, where all fundamental material properties and functions would be efficiently established and changed.

Five basic "Metrics" (NNI proposal, RD1 - 1999)

1. **Systematic control of matter at the nanoscale**

   2004: COV / NSF Evaluation → the progress is on target

2. **New products and processes that were not possible before because of technical or economical barriers**

   2004: Commercialize novel materials → the progress is on target

R&D towards the Next Industrial Revolution

1999 metrics, 2004 check the progress, 2015 to satisfy first criteria

3. Half of the new products in advanced industrial area (materials, electronics, pharmaceutics, chemicals, aeronautics, devices for molecular medicine) will use nanoscale S&E

2004: Survey industry, SI report → At least half by 2015

4. $1 trillion world market of products with key component based on nanotechnology, 2 million jobs worldwide

2004: Increasingly supported by studies → On of before 2015

5. Establish an interdisciplinary community (called "grand coalition" in RD1) and suitable workforce

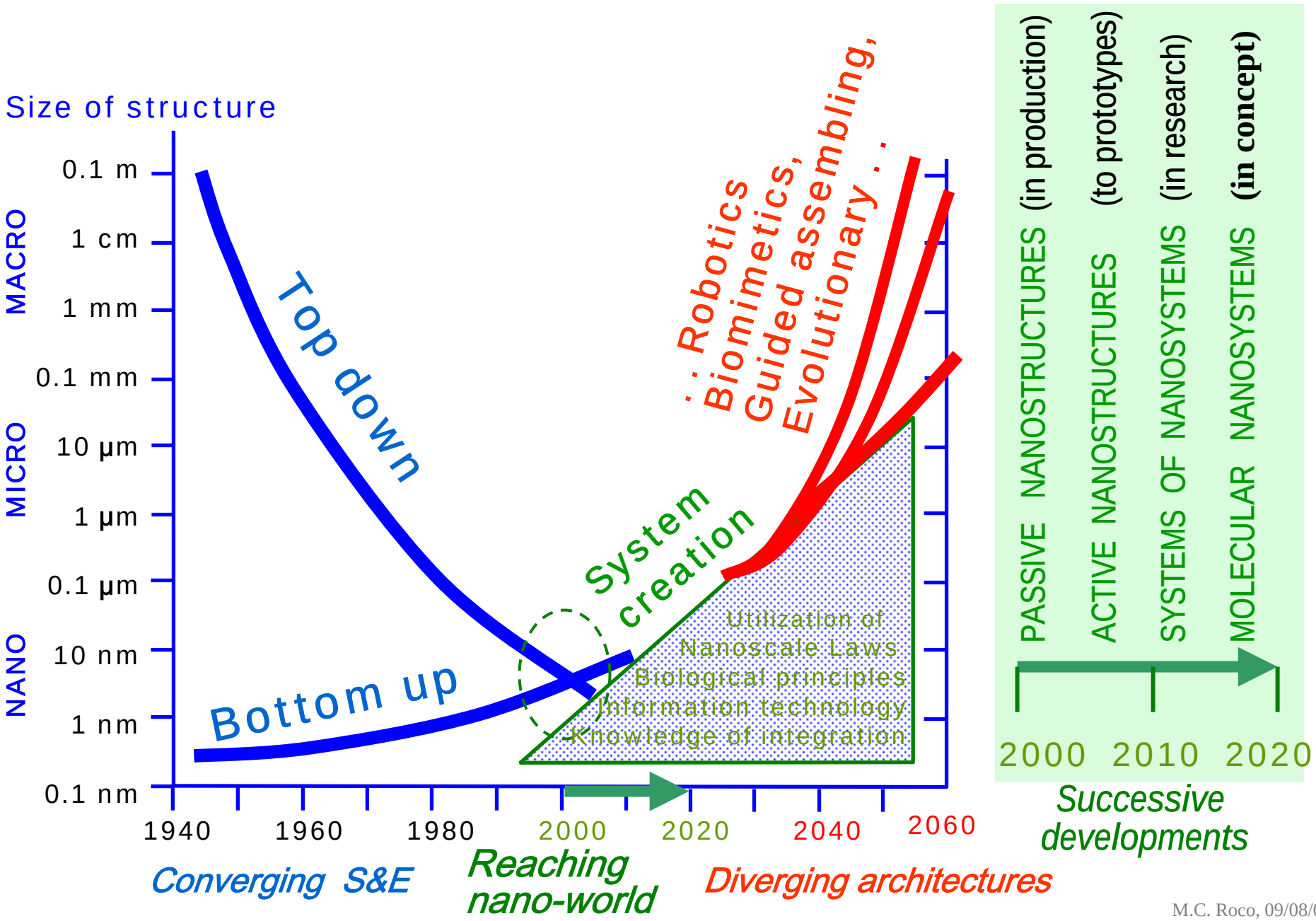
2004: COV / NSF evaluation → "a big achievement"

NRC evaluation in 2002 - good strategic view

Industry / academia / Federal government / state partnerships

Systemic changes and earlier NT education, workforce

Reaching nano-world and system creation



M.C. Roco, 09/08/04

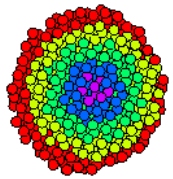
10-20 years vision

Timeline for beginning of industrial prototyping and commercialization

Increased integration, system approach

Converging science and engineering

- **1st Generation:** Passive nanostructures **~ 2001**

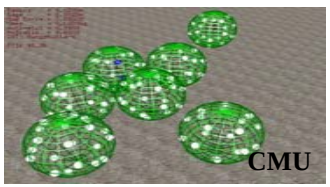


Ex: coatings, nanoparticles, nanostructured metals, polymers, ceramics

- **2nd Generation:** Active nanostructures **~ 2005**

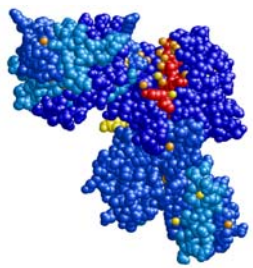
Ex: transistors, amplifiers, targeted drugs, actuators, adaptive structures

- **3rd Generation:** Systems of nanosystems **~ 2010**

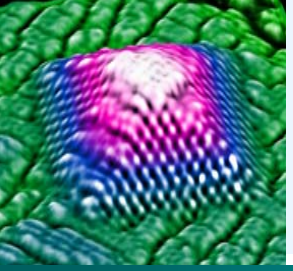


Ex: guided molecular assembling; 3D networking and new system architectures, robotics, supramolecular

- **4th Generation:** Molecular nanosystems **~ 2020**



Ex: molecules as devices/components 'by design', based on atomic design, hierarchical emerging functions, evolutionary systems

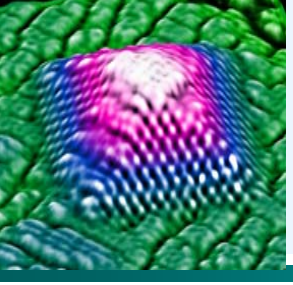


NATIONAL NANOTECHNOLOGY INITIATIVE

- Timeline (Preparing NNI) -

- March 1991 "Nanoparticle Synthesis and Processing" (NSF program)
- Nov. 1996 Nanotechnology Group (bottom-up)
- March 1998 Functional Nanostructures; Partnership in nanotechnology (NSF in collaboration with other agencies)
- **Sept. 1998 NSTC establishes Interagency Working Group of Nanoscience and Engineering (IWGN)**

- March 1999 OSTP/CT presentation on NNI, Indian Treaty Room
- May-Sept. 1999 Congress hearings; Three publications NSTC/IWGN; Nanotechnology R&D planning in six agencies IWGN planning for NNI
- Oct. – Dec. 1999 OMB review – NNI the only new topic recommended PCAST – Letter to the President supporting NNI OSTP and WH Approval
- **Jan. 2000 NNI announced by the President in Jan 2000**



NATIONAL NANOTECHNOLOGY INITIATIVE

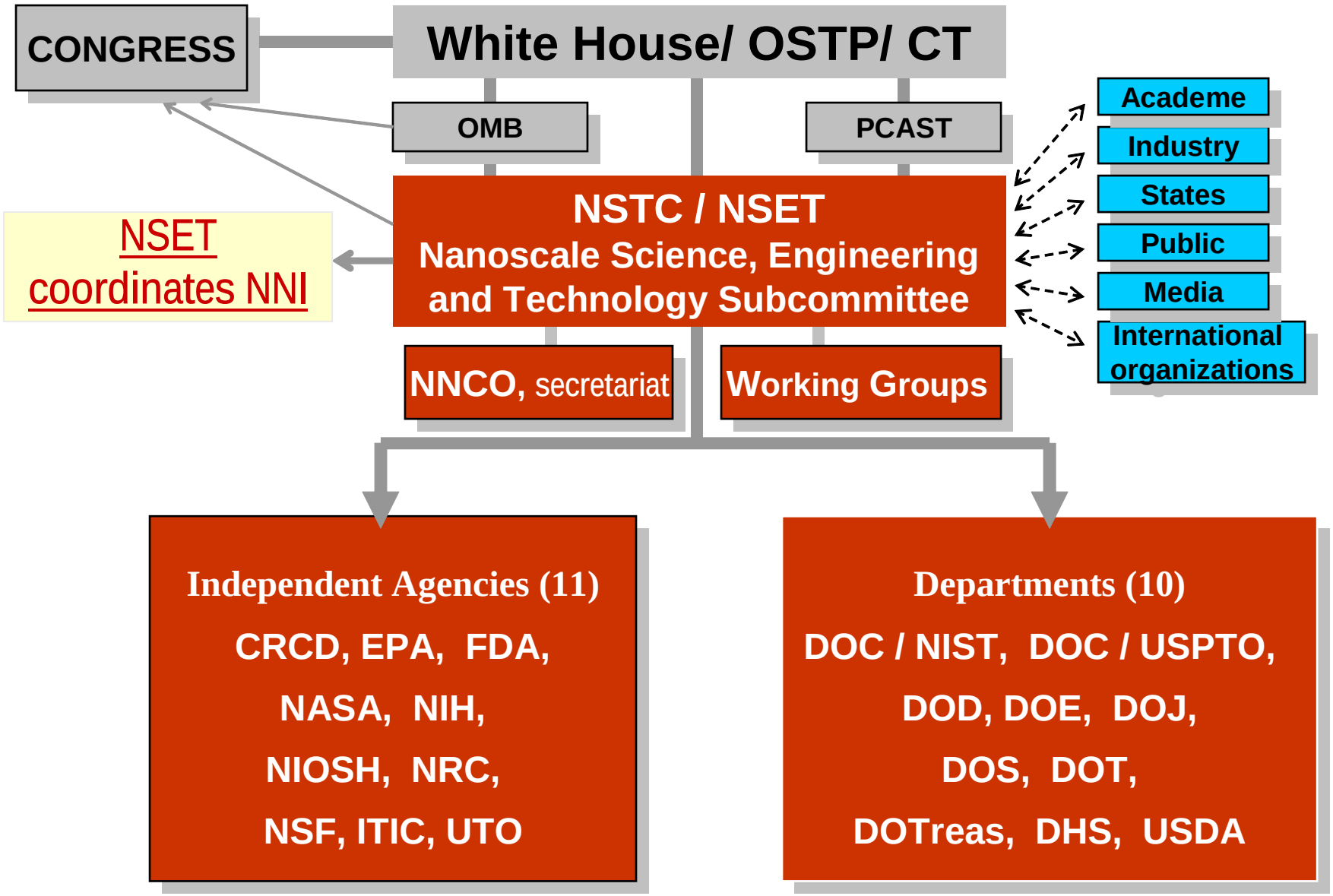
- Timeline fiscal years (FYs) 2001-2004 -

- **Feb. – Dec.. 2000: WH Congress review and approve FY 2001 NNI**
  NSTC establishes NSET for implementating NNI, Oct. 2000
  "Societal Implications" workshop in Sept. 2000
- **FY 2001** **6 agencies;** actual investment **$465M**
  Concerns about the interest, "science fiction" perception
  MOU to establish NNCO, Jan. 2001
- **FY 2002** **12 agencies**; actual investment **$697M**
  International reaction: programs in 30 countries
  Industry get involved in many sectors
  20 states and regional alliances begin to invest
- **FY 2003** **16 agencies** ; actual investment **$862M**
  Outcomes: research, education, industry and
  states investments, patents, IPO; GMO perspective
- **FY 2004** **21 agencies,** WH Request - **$961M;**
  2 Bills in Congress for FY04-08; The President signs
  Public Law 108-153 "21st Century NT R&D Act"
  Letter from OSTP-OMB with NNI as a priority

Goals of the NNI

- **Conduct R&D to realize the full potential of this revolutionary technology**

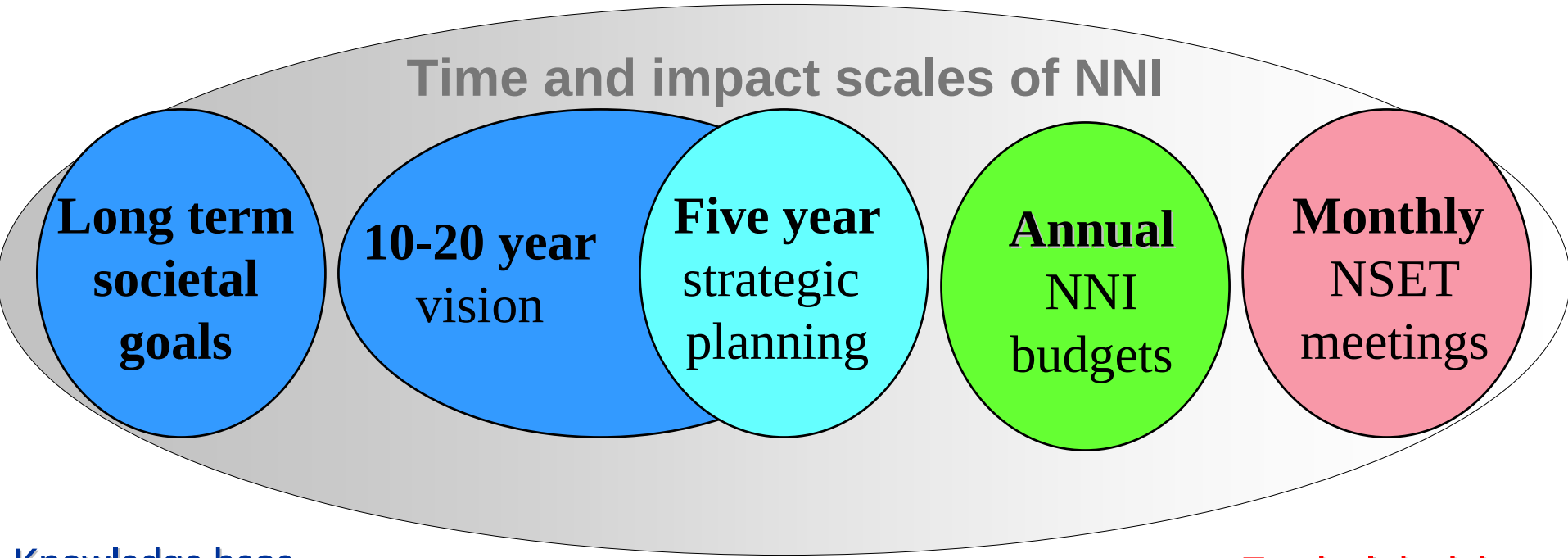
  It includes: Extend the frontiers of nanoscale science and engineering though support for research and development; Maximize return on Federal government's investment in nanoscale R&D through coordination of work of participating Federal agencies and partnerships
- **Develop the skilled workforce and supporting infrastructure needed to advance R&D**
- **Facilitate transfer of the new technologies into commercial products**
- **Understand better the social, ethical, health, and environmental implications of the technology**
- **Ensure U.S. global competitiveness and leadership in the development and application of nanotechnology**



National Nanotechnology Initiative coordination

(Levels: National / Federal agencies, Each agency / Partnerships with industry, states, regional, international / Interaction with public, media)

The long-term vision drives NNI



Knowledge base
New technology
Quality of life
Responsible NT
World context

1999 Research Directions I
2004 Research Directions II
10 topical reports in 03-04
Evaluation PCAST, NRC

Annual budgets
FY 2001, .. , 2005
OMB crosscut
EOP evaluation

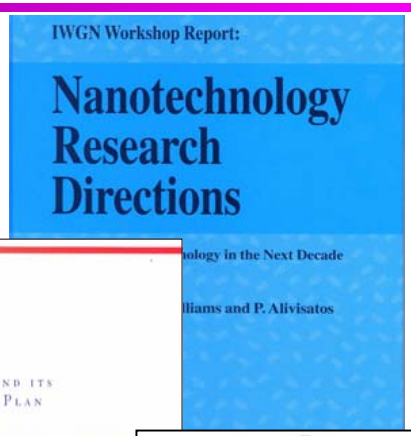
Tactical decisions
Programs
Partnerships
Safety issues

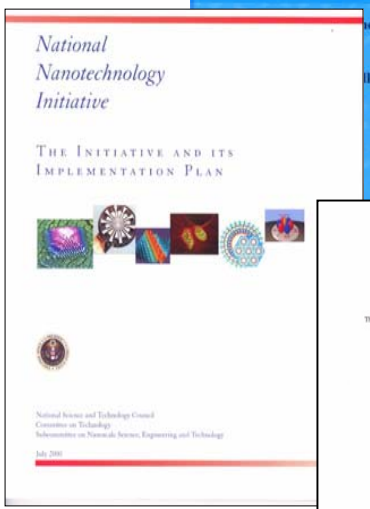
Defining the vision (I)

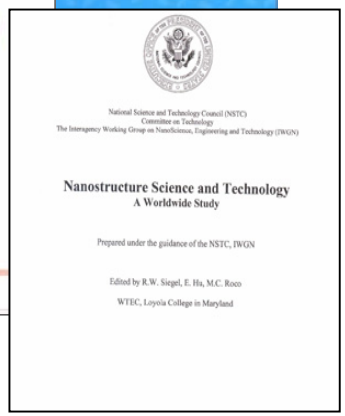
National Nanotechnology Initiative

1999-2000

1999: 10-year vision



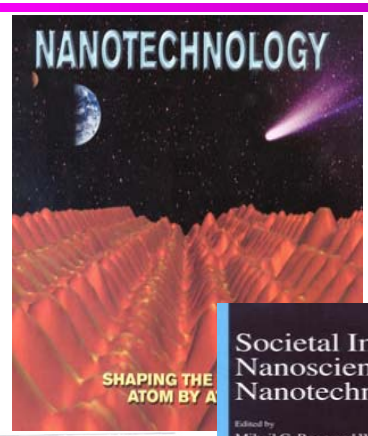




Government plan

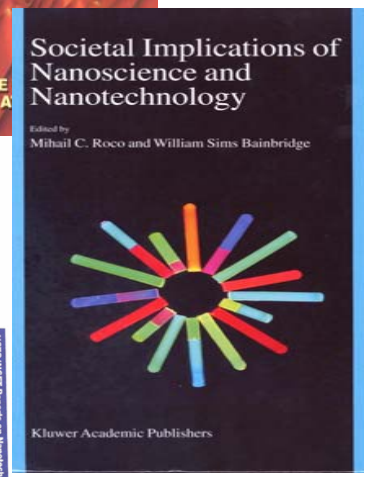
Worldwide benchmark

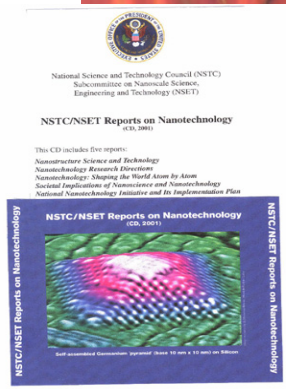
Reports



Brochure for public

Societal implications





FY 01-05: RD1 provides a foundation for annual NNI plans

June 2002: "Review of NNI" by U.S. Academies for WH/OSTP

Focus on Knowledge Creation: same principles, phenomena, tools, architectures to support innovation in various areas of relevance

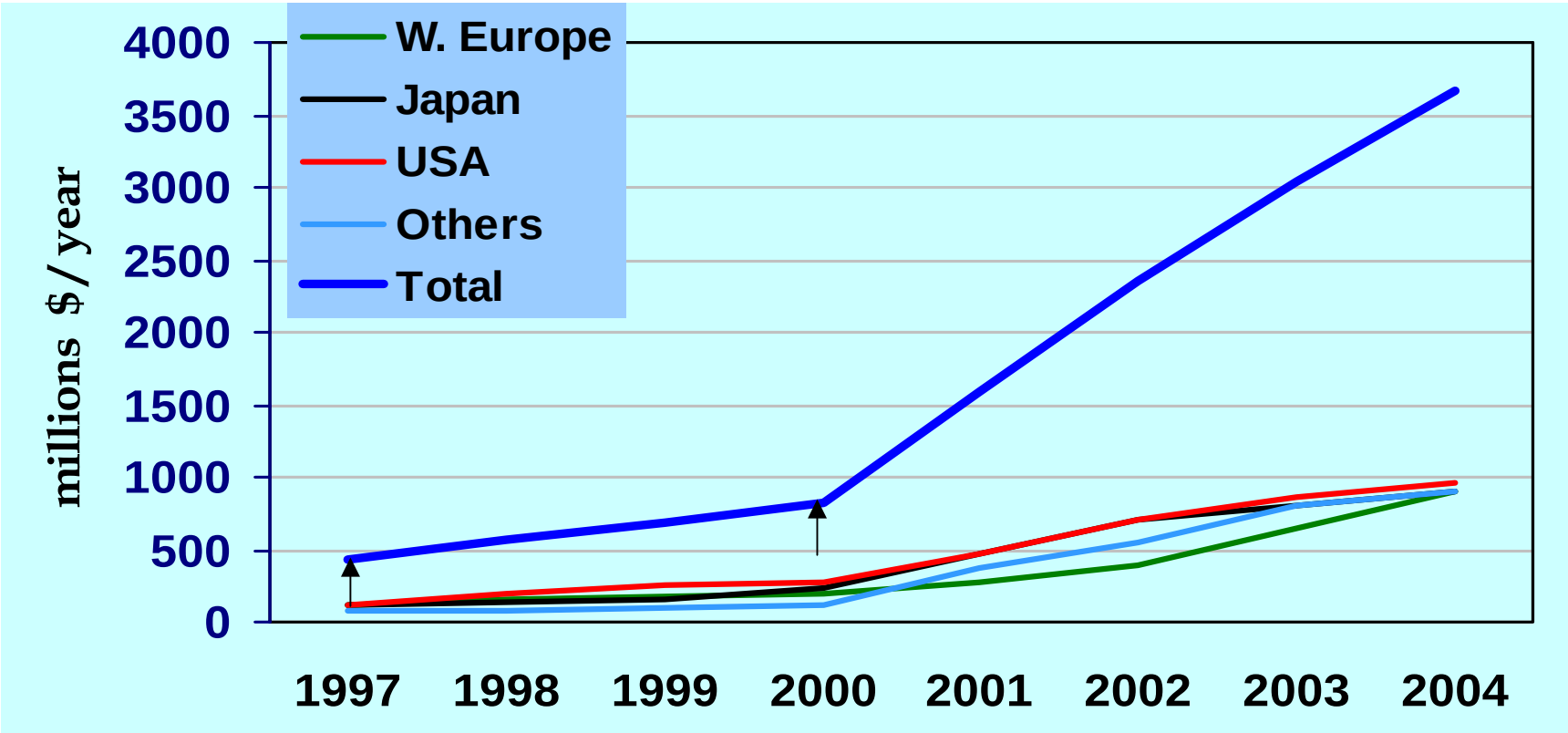
NNI: R&D Funding by Agency

Fiscal year (all in million $)	*2000* Actual	*2001* Enact/Actual	*2002* Enact/Actual	*2003* Enact/Actual	2004 Req./ Enact	2005 Req
National Science Foundation	97	150 /150	199 /204	221 /221	249 /254	305
Department of Defense	70	110 /125	180 /224	243 /322	222 /315	276
Department of Energy	58	93 /88	91.1 /89	133 /134	197 /203	211
National Institutes of Health	32	39 /39.6	40.8 /59	65 /78	70 /80	89
NASA	5	20 /22	35 /35	33 /36	31 /37	35
NIST	8	10 /33.4	37.6 /77	66 /64	62 /63	53
EPA	-	/5.8	5 /6	5 /5	5 /5	5
Homeland Security (TSA)	-		2 /2	2 /1	2 /1	1
Department of Agriculture	-	/1.5	1.5 /0	1 /1	10 /1	5
Department of Justice	-	/1.4	1.4 /1	1.4 /1	1.4 /1	1
TOTAL	270	422 /465	600 /697	770 /862	849 /961	982
		+72%	+50%	+24%		

- Industry, state and local organizations: about 1.5 times NNI budget in 2003
- 21 NSET departments / agencies, including: OSTP, NSTC, OMB, DOC, DOS, DOT, DOTreas, FDA, NRC, DHS, IC, NIOSH, USPTO; partnerships with others
- NNI budget: 65% to academia; 25% - R&D labs; 10% - industry (7% SBIR)

Context – Nanotechnology in the World

Past government investments 1997-2004 (est. NSF)



Note:

- U.S. begins FY in October, six months in advance of EU & Japan (in March/April)

NNI implementation plan published in July 2000

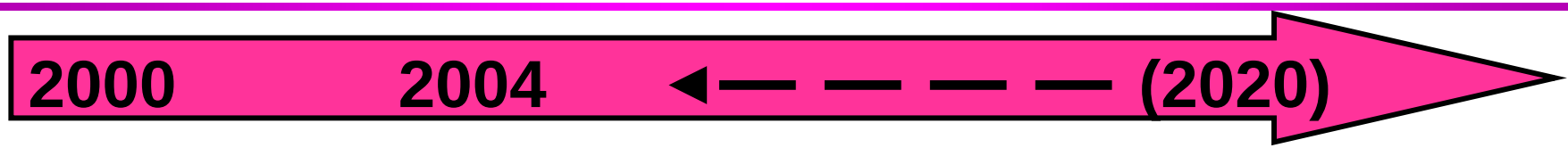
Major changes in the first 3 years of NNI (Part 1)

- **Research**: **NNI supports about 2,500 active awards in about 300 academic organizations and 200 private organizations in all 50 states**; **Developments faster than expected: Reducing the time of reaching commercial prototypes by at least of factor of two for several key applications. Half of world HI papers. Setting new goals.**

- **Education**: **7,000 students and teachers trained in 2003; All science and engineering colleges have introduced courses related to NSE. Earlier nanotechnology education.**

- **Significant infrastructure**: **in over 60 universities with user capabilities; Five networks (NCN,NNIN, OKN, DOE, NASA) have been established. About 40,000 workers**

At the beginning of NNI
R&D targets set up in 2000 towards 2020



10 key advancements set up in 2000

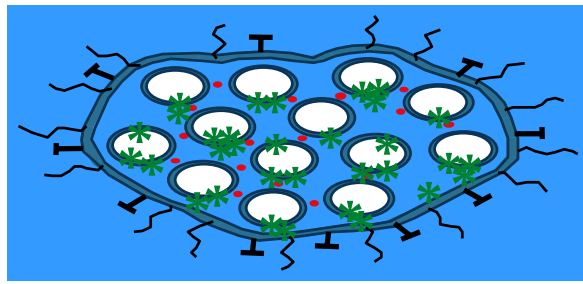
- Engineer materials with atomic precision using biosystems as agents
- Create circuits with the logic element a molecule wide
- Assemble DNA, nanocrystals to build molecular devices and systems
- Detect anthrax, other contaminants with unprecedented speed
- Single molecule behavior and interaction
- Artificial genetic system
- Conducting polymers
- New concepts for large scale production of nanotubes, their use
- Drug delivery systems
- Detection of cancer

NNI results faster than expected in 2001-2004: reducing the time of reaching commercial prototypes by at least of factor of two for several key applications

Example:

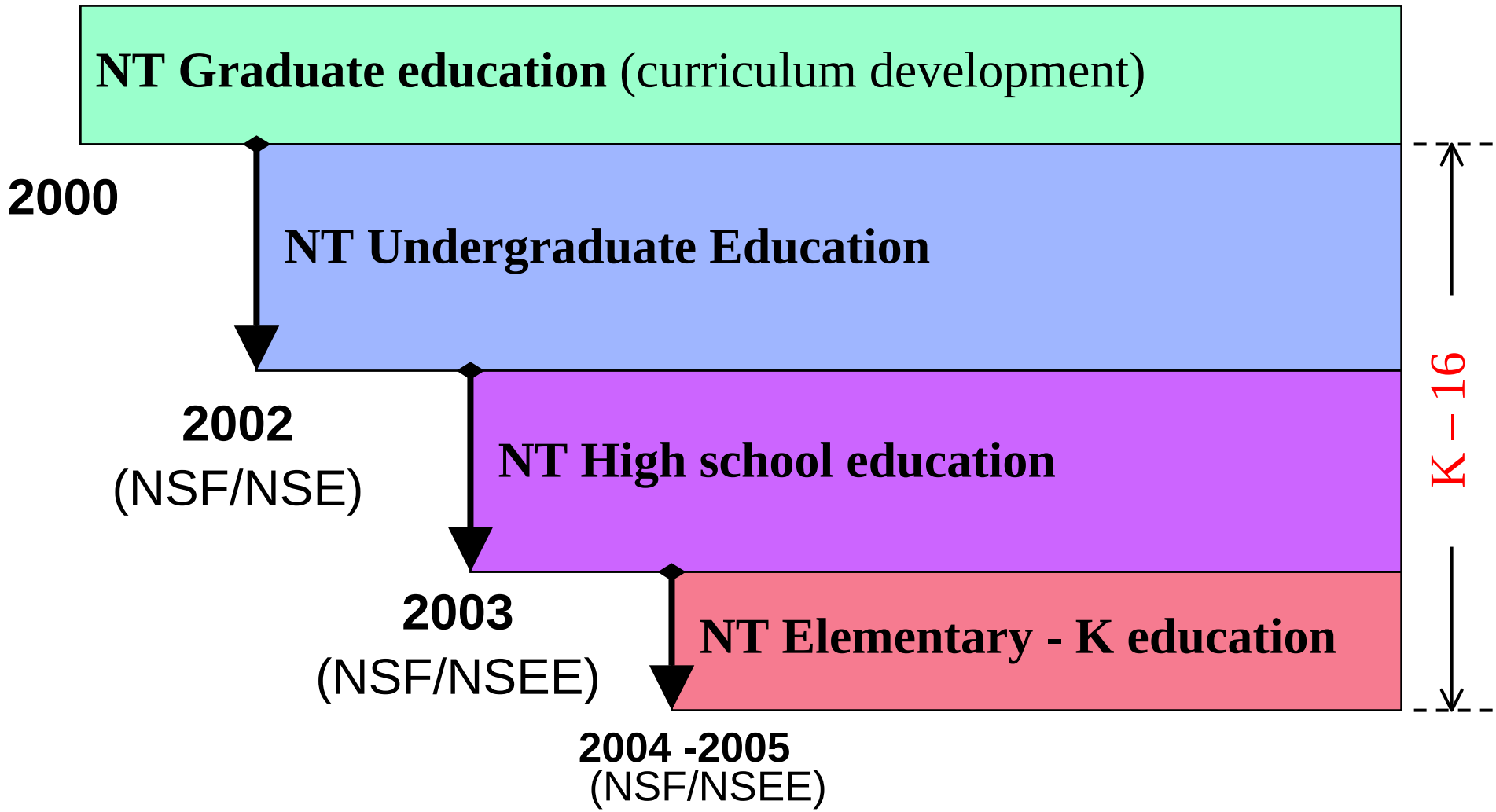
Synthesis and control of nanomachines

(examples NSE in 2004, www.nseresearch.org - 250 projects)



- **Self-assembly processing** of nanoscale bio-materials and devices for micromachines components (UCSB)
- Chemistry to synthesize components of **nano machines to work on surfaces** and be activated by external electromagnetic fields (UCB)
- **Light driven molecular motors** (U. Nevada)
- **Combinatorial engineering of nanomachines**, with application to membranes and filters (U. Penn.)
- **Nanoengineering surfaces** for probing viral adhesion (UC Davis)

Introducing earlier nanotechnology education
(NSF: Nanoscale Science and Engineering Education)



Grand Challenges (NNI, FY 2003 est.)

- Nanostructured materials "by design" ~ 22%
- Nanoelectronics, optoelectronics and magnetics **39%**
- Advanced healthcare, therapeutics, diagnostics 8%
- Environmental improvement **4%**
- Efficient energy conversion and storage 4%
- Microcraft space exploration and industrialization 3%
- CBRE Protection and Detection (revised in 2002) 6%
- Instrumentation and metrology 6%
- Manufacturing processes 8%

(details in the NNI Implementation Plan, http://nano.gov)

Infrastructure Outcomes of 2001-2003: R&D Networks and User Facilities

- **Network for Computational Nanotechnology** (NCN)
  - **7** universities (Purdue as the central node)
  - Nanoelectronic device simulation/modeling
- **National Nanotechnology Infrastructure Network (NNIN)**
  - 13 universities with user facility
  - Development measuring & manufacturing tools, including NEPM
  - Education and societal implications
- **Oklahoma Nano Net (EPSCoR award)**
- **DOE network for large scale facilities: 5 National Labs**

29 new centers and networks supported by NNI since 2001:

17 NSF, 5 DOE, 3 DOD, 4 NASA (at universities); continuing MRSECs

NNI implementation plan published in July 2000

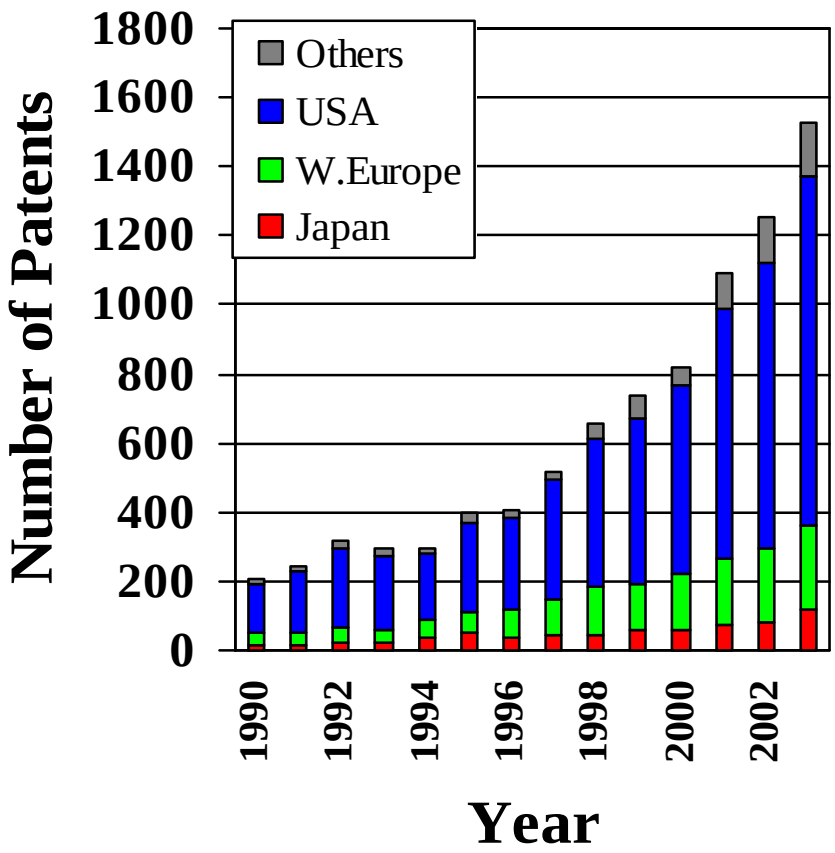
Major changes in the first 3 years of NNI (Part 2)

- **Industry:** about the same level of investment as NNI in medium and long-term research; Investment by large companies; From "if?" to "how?" and "who will lead?"
- **Innovation and venture funding:**
  US has over 5,000 patents using NSE in 2003 with USPTO (2/3 world)
- **Estimation on revenues from nanotechnology:**
  Reaching $1trillion in 2015 worldwide, and the estimations moving closer because of accelerated development; growth >25% per year
- **States and regional alliances:** "meltdown" in 2002 -
  > 20 states committed funding, > 22 regional alliances

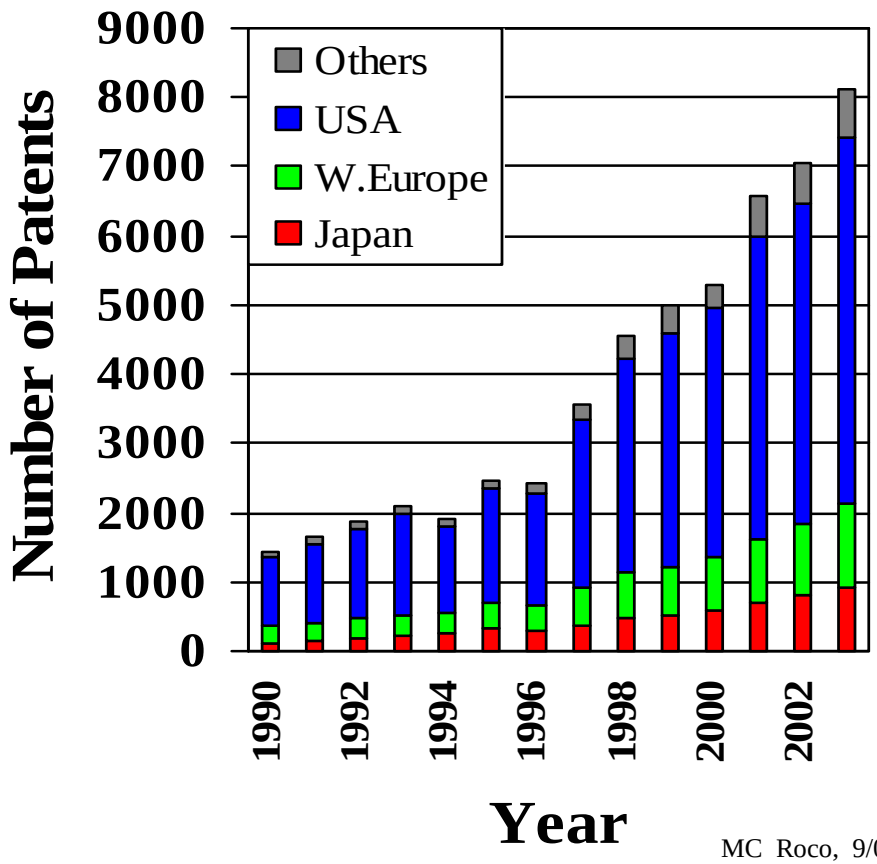
US has about 2/3 of world NT Patents (USPTO database)

using "Title-claims"and "Full-text" search for nanotechnology by keywords
(using intelligent search engine, after J. Nanoparticle Research, 2004, Vol. 6, Issue 4)

"Title-claims" search:
nanotechnology claims



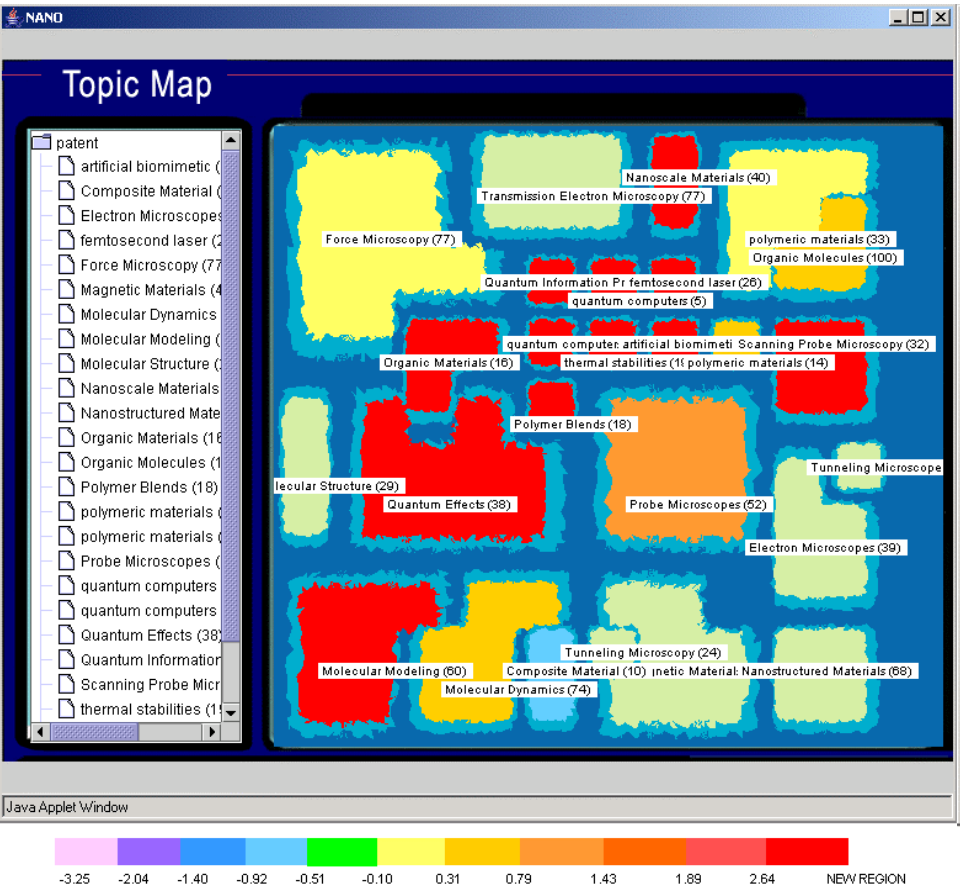
"Full-text" search:
nanotechnology claims,
or/and NSE tools and methods



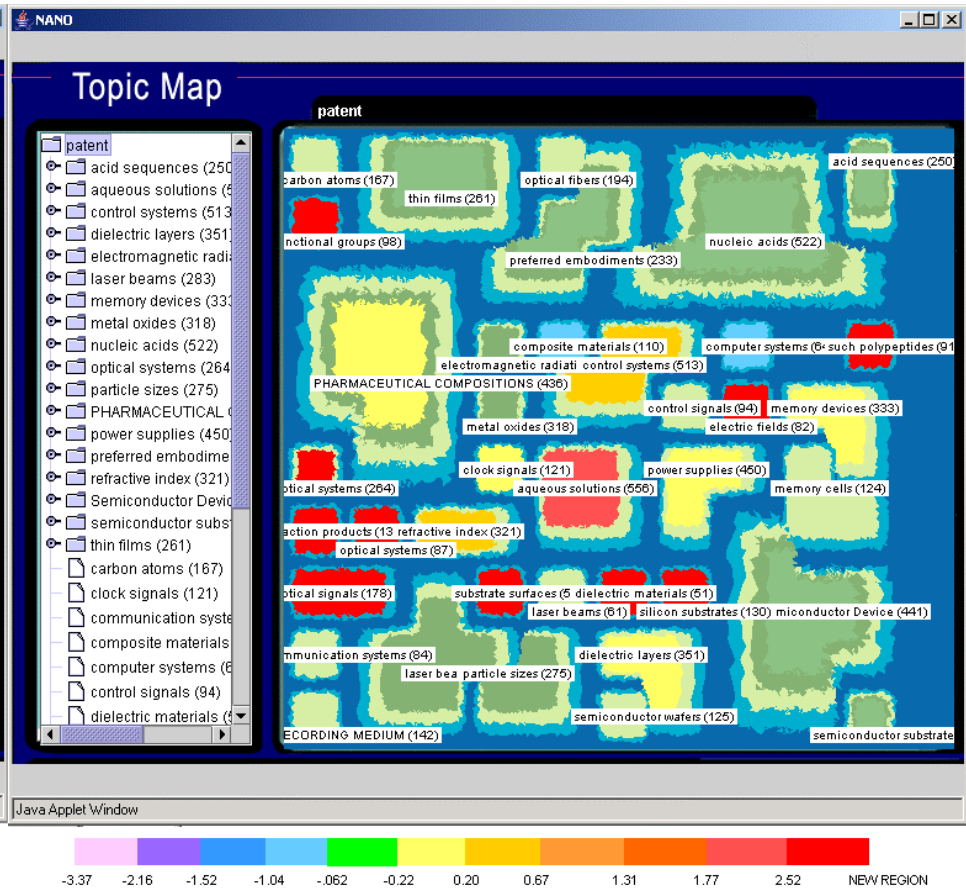
MC Roco, 9/08/04

NSE content map analysis
grant – patent topic association

NSE Grant Content Map (2001-2002)



NSE Patent Content Map (2001-2002)



Region color indicates the relative growth rate (red – highest rate)*

(source: NSF sponsored research)

NNI-Industry Consultative Boards for Advancing Nanotech

Key for development of nanotechnology, Reciprocal gains

- **NNI-Electronic Industry (SRC lead), October 2003**
  - Collaborative activities in key R&D areas
  - 5 working groups, Periodical joint actions and reports
  - NSF-SRC agreement for joint funding; other joint funding

- **NNI-Chemical Industry (CCR lead)**
  - **Joint road map for nanomaterials R&D**
  - **2 working groups, including on EHS**
  - **Use of NNI R&D results, and identify R&D opportunities**

- **NNI – Organizations and business (IRI lead)**
  - **Joint activities in R&D technology management**
  - **2 working groups (nanotech in industry, EHS)**
  - **Exchange information, use NNI results, support new topics**

- **In developments: NNI - Pharmaceuticals (Phrma lead)**
  NNI - Automotive industry

Industry surveys

- Companies working in nanotechnology

Survey by Small Times in 2004, based on individual contacts and direct verification:

875 nanotech companies

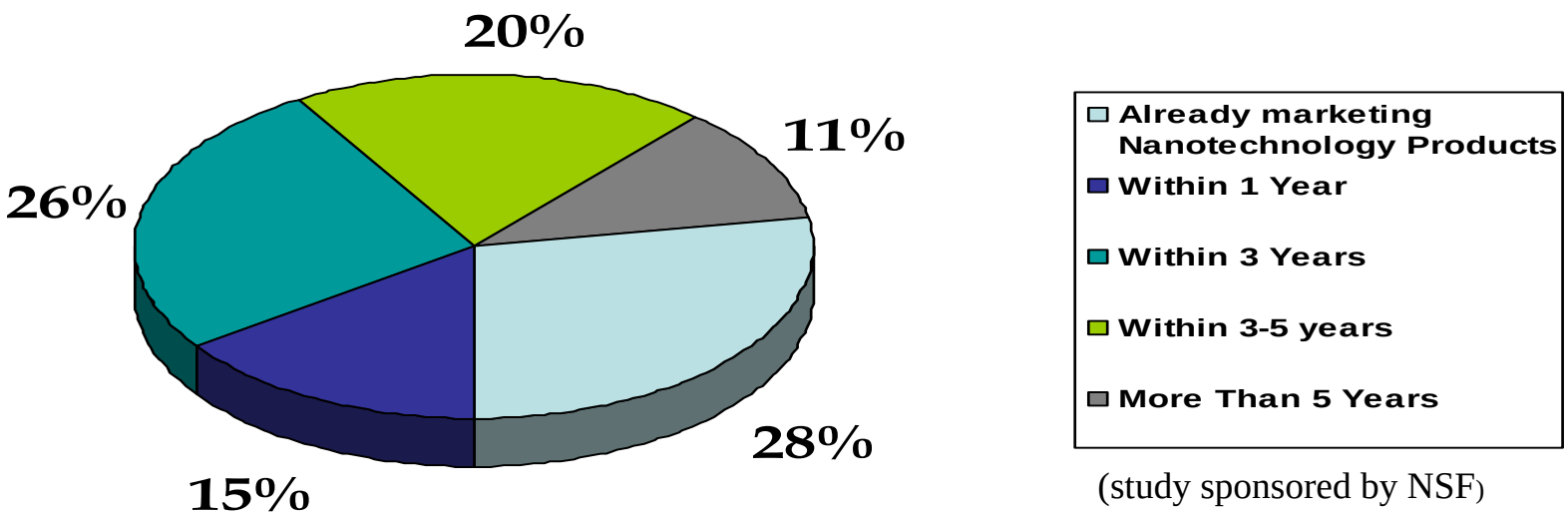
475 products in 215 companies

- Timeline for commercialization

Survey by National Center for Manufacturing Sciences:

81 manufacturing companies:

89% expect products in less than 5 years



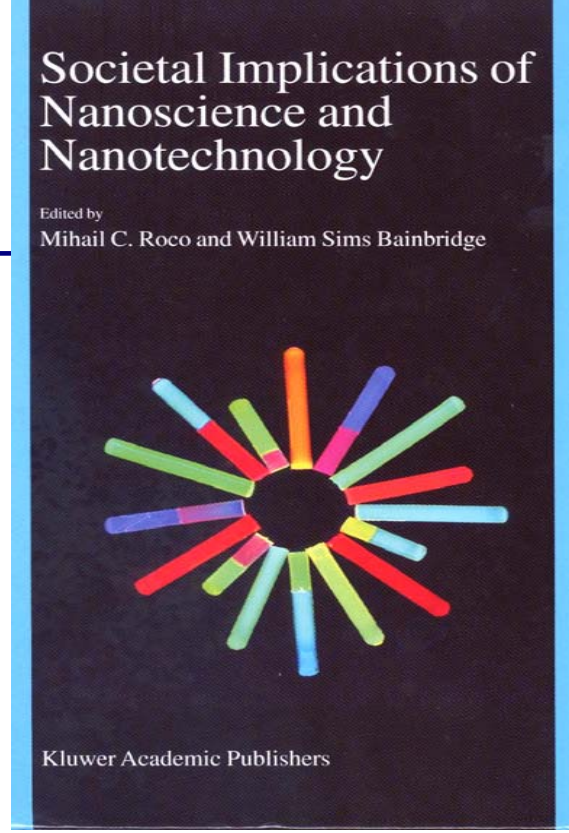
(study sponsored by NSF)

NNI implementation plan published in July 2000

Major changes in the first 3 years of NNI (Part 3)

- **Professional societies**: Specialized divisions, workshops, education; AAAS, ACS, APS, MRS, ASME, AIChE, IEEE, AVS, other major societies in the race
- **Government investment**: Worldwide investment has increased 7 times in 6 years reaching $3B in 2003 (of which US $0.77B and NSF $0.22B)
- **Societal implications from the beginning**: Workshop on Societal Implications of Nanoscience and Nanotechnology in 2000; NSF programs on SI since 2000
- **Other broader implications**: In Federal Government (NNI), Legislative (5 year Bill), Judiciary branches, cultural

Societal Implications: Follow-up of the September 2000 report



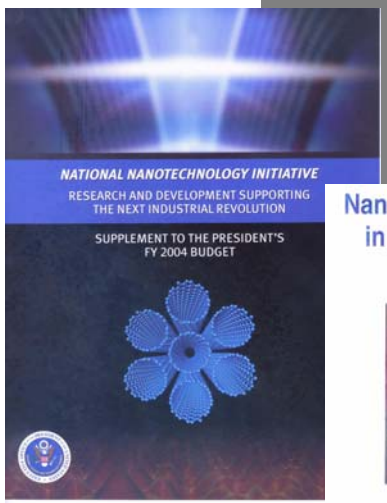
- Make support for social, ethical, and economic research studies a priority:
  (a) New theme in the NSF program solicitations;
  (b) Centers with societal implications programs;
  (c) Initiative on the impact of technology, NBIC, HSD
- NNCO – communicate with the public and address EHS, unexpected consequences http://nano.gov
- NEHI working group of NSET has been established in 2003
- Basic reference for the interaction with the public
- Converging technologies from the nanoscale
- Workshop with EC (2001); Links to Europe, Americas, Asia

Defining the vision (II)

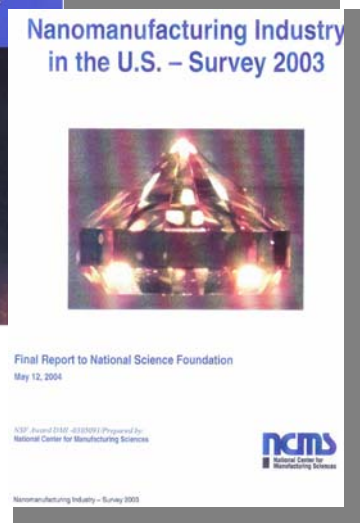
National Nanotechnology Initiative

2004

2004:
10-year
vision

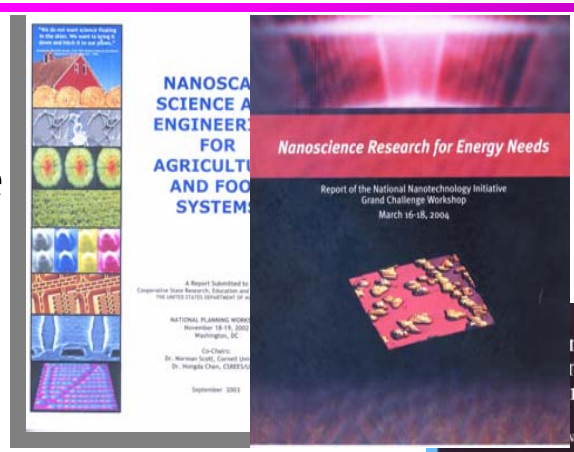


Government
Plan (annual)



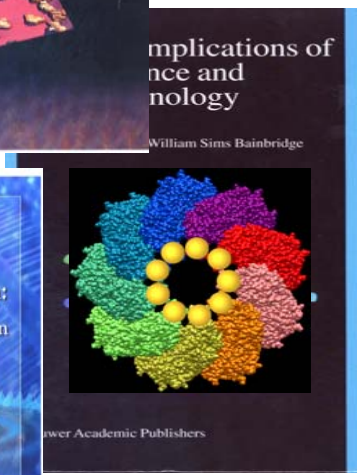
Survey
manufacturing

Agriculture
and Food

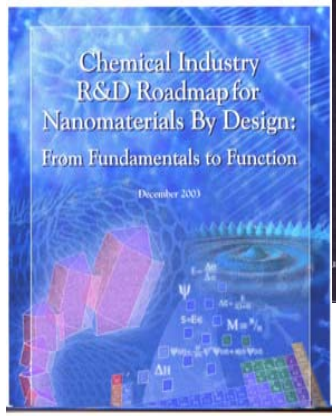


Energy

Societal
Implications
2004



Reports



Other topical reports
on www.nano.gov

2004: Update 10 year vision, and develop strategic plan

After 3 years of NNI:
New R&D potential targets for 2015 (ex.)

2004 **2015**

Nanoscale visualization and simulation of 3D/m domains

= Micro domains with nano space and time resolutions

Transistor beyond/integrated CMOS under 10 nm

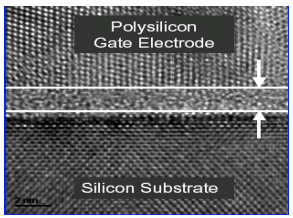
New catalysts for chemical manufacturing

No suffering and death from cancer when treated

Control of nanoparticles in air, soils and waters

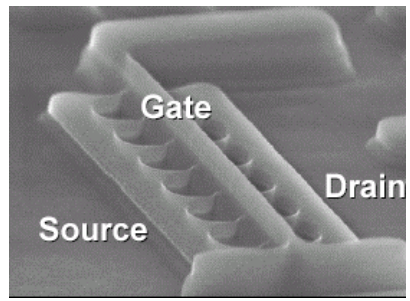
Challenge: Transistor beyond/integrated CMOS under 10 nm – 2015

- In the 70s, 80s and 90s
  Geometrical scaling was the major driver
- In the 2003 - 2012 period (industry target)
  Use of novel physical phenomena to extend performance by equivalent scaling are the major drivers. Examples (2004):



1.2 nm gate oxide is ~5 Silicon atom layers thick

"Strained Silicon" - Separating the Silicon Atoms for Faster Electron Flow



Tri-gate Transistor

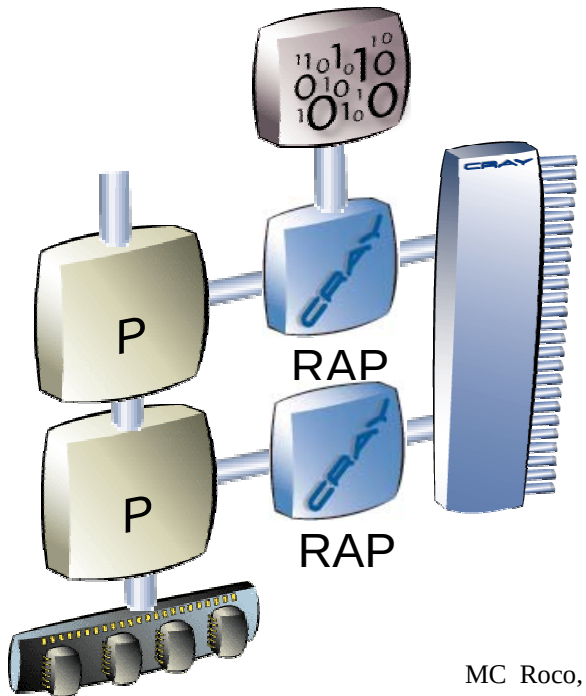
In addition, to explore beyond CMOS:

- New carriers instead of electron charge
- Integrate CMOS with other nanodevices
- New system architectures
- Integration with applications

Challenge 2015: To simulate engineering problems from basic principles at the nanoscale

Using nanotechnology to build the highest speed processors

Using fast computers and reconfigurable computing for nanoscale S&E "application acceleration" (for 100x potential speeedup)

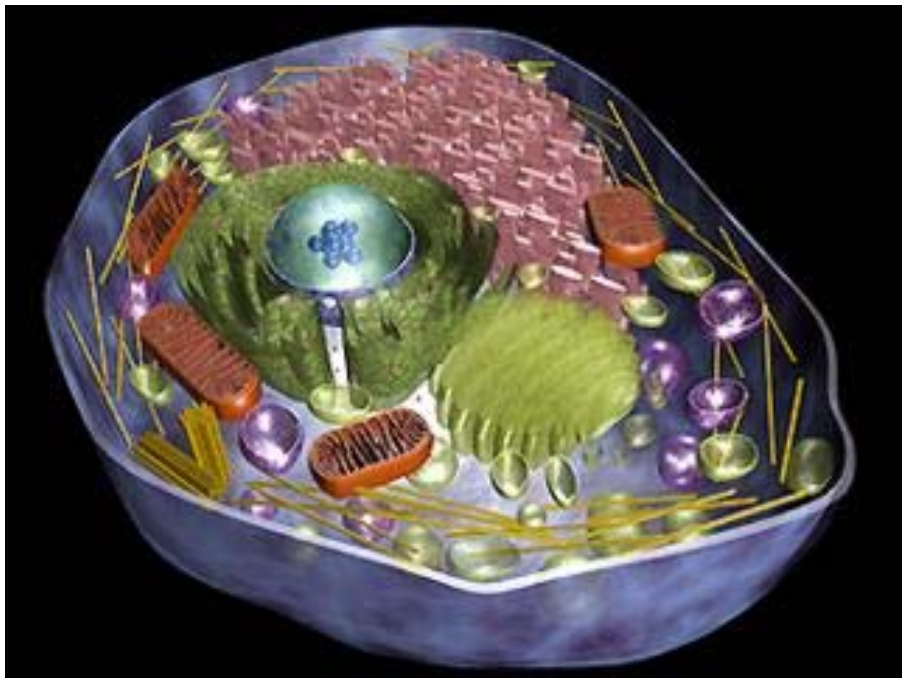


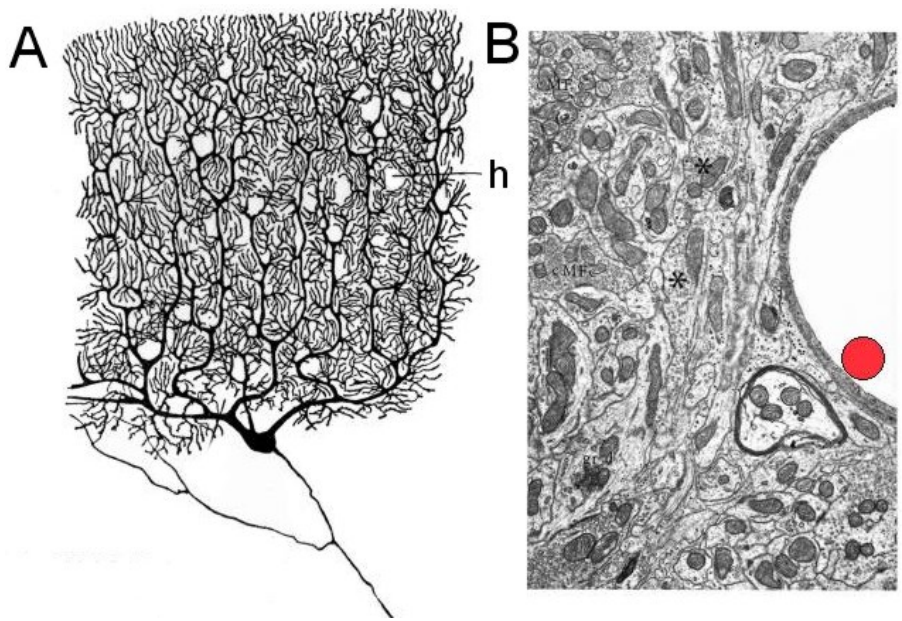
Capability 2004 (Cray X1):
50+ TFLOPS (fastest computer in the world)

~ 2010 (Cray Cascade):
DARPA – NSF – DOE acad. support
1,000+ TFLOPS

~ 2015 (Cray target):
10-100,000 TFLOPS

Challenge 2015: Specify the state of a cell and of nervous system from the nanoscale





R. Llinas, 2003

The Cell

– the machinery of life

The brain

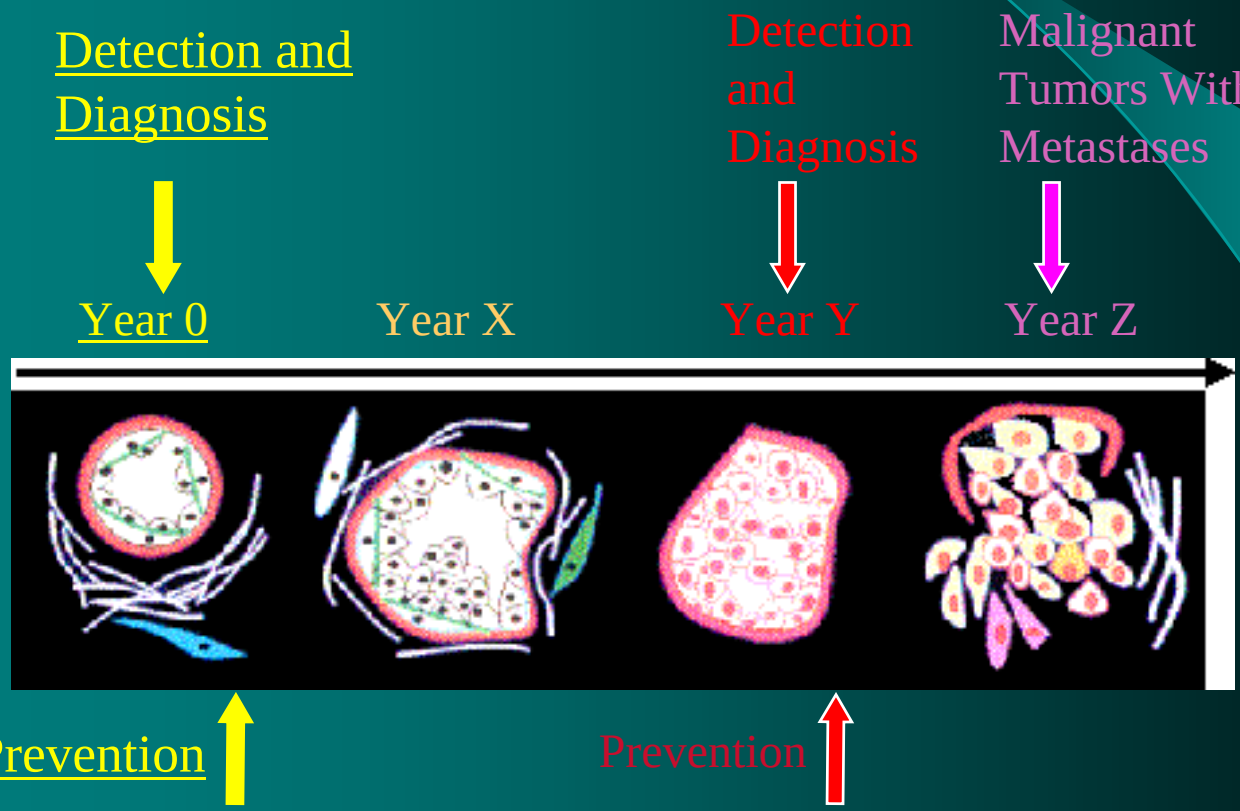
– system based on nanoscale processes

Measure and simulate, 3 dimensional, highly parallel, . . .

Challenge 2015: To Eliminate Suffering and Death Due to Cancer

"A Vision Not a Dream!" by using nanotechnology, A v. *Eschenbach, NCI*

Where We Want To Be ← Where We Are



Cancer results from accumulation of multiple genetic changes in a cells.

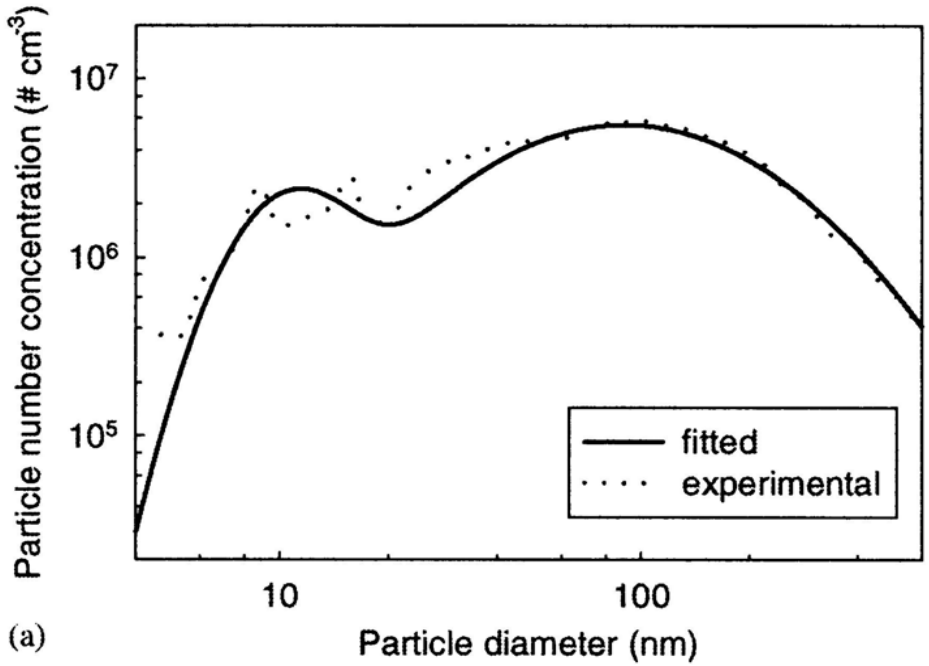
Nanotechnology will allow earlier detection and prevention (Year 0)

Environmental issues related to nanotechnology include:

- Sustainable development, life-cycle of products, measurement and mitigation, clean-up techniques, global effects
- Combustion, welding, water/air filtration, cell behavior, toxicity

Programs since 2000
The programs need long duration for impact
Big challenges ahead to be addressed in this workshop

Zimmer et al., 2002



After 3 years of NNI:

New R&D potential targets for 2015 (2)

2004 **2015**

Advanced materials and manu.: ½ from molecular level

Pharmaceuticals synthesis and delivery: ½ based on nano

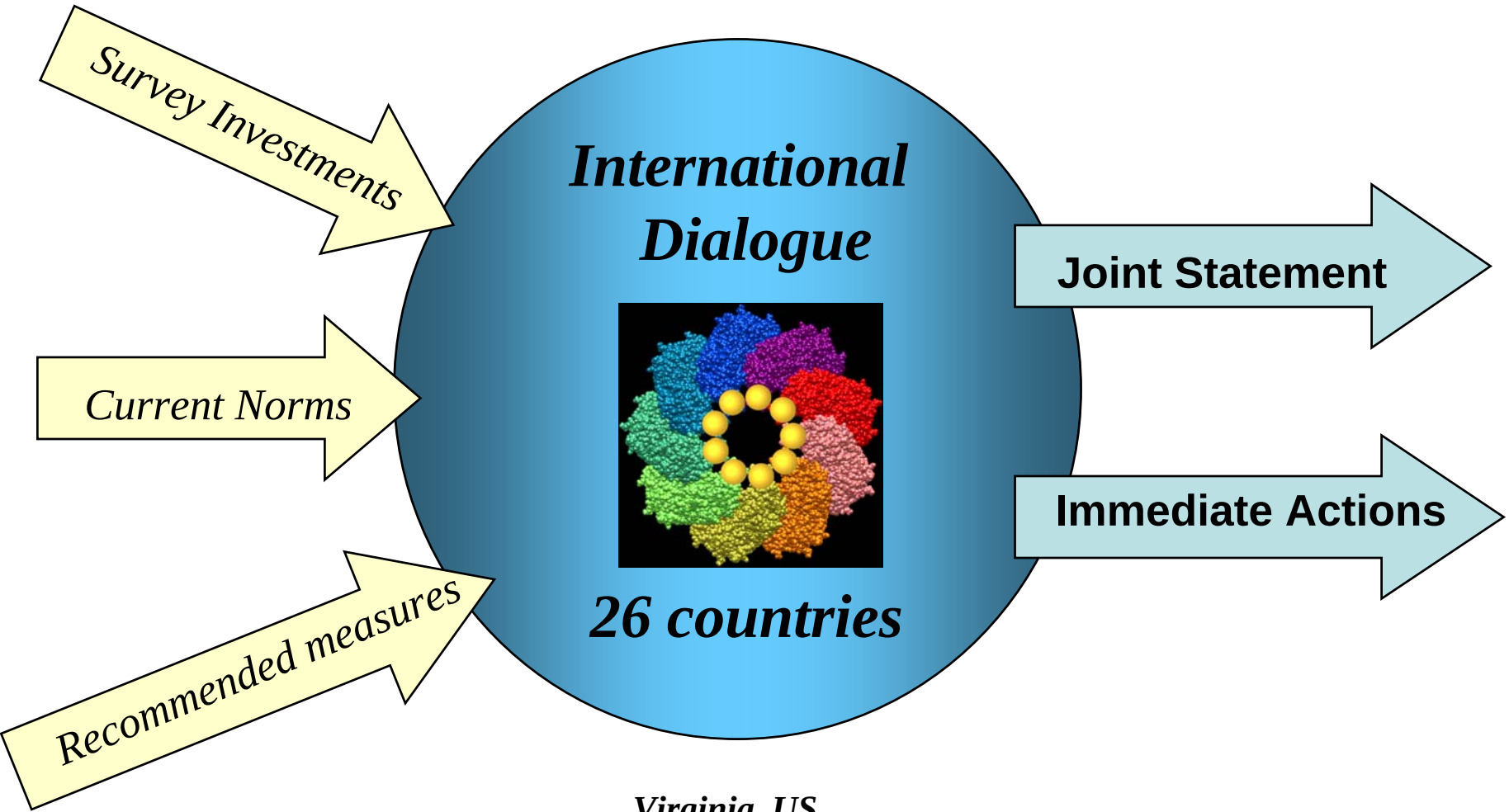
Converging technologies from the nanoscale

Including: artificial organs, manufacturing multidisciplinary platforms, etc.

Life-cycle biocompatible/sustainable development

Education: nanoscale instead of microscale-based

International Dialogue for Responsible Nanotechnology R&D



Virginia, US

June 17-18, 2004

MC. Roco, 9/08/04

NNI challenges

- **Need for coherent, exploratory, long-term (5-10 yr) plans**
- **Responsible development of nanotechnology**
- **Horizontal versus vertical S & T development:**
  0.3% (in 2000) - 0.8% (in 2004) for basics, versus
  5% (est. for basics + precompetitive R&D) of US R&D
- **Competitiveness: Strengthening partnership w/ industry**

  Need for system-oriented programs, focused on topics such as: the new transistor <10nm, new display, new catalyst, conditioning the cell, S&T convergence

  Support: Joint R&D in university-industry networks and industry-government laboratories to facilitate new technologies and commercialization

Key objectives

(NNI RD2)

Visionary goals
of national
interest realizable
in 10-20 years

Transforming strategies
and R&D priorities
to reach those goals